Method for establishing a binaural communication link and binaural hearing devices

The present invention is directed on linking a pair of hearing devices to form a set of binaural hearing devices. Such hearing devices may be therapeutic hearing aid devices for hearing impaired persons or may be hearing devices just for improving human hearing or for allowing listening to electronically converted audio signals as e.g. for telephone ear-sets, ear-sets in airplanes or even noise protection hearing devices, thereby possibly for active noise cancellation.

Today known binaural links between a pair of hearing devices are impaired by the severe requirements at hearing devices and thereby especially at hearing aid devices with respect to electric power consumption. There has been proposed to establish such a binaural wireless communication link in the RF-frequency band or even in the microwave frequency band. Thereby satisfyingly small receiving and transmission aerials may be used, but the power consumption for the transmitter and the receiver is considerable.

A communication link approach at lower transmission frequencies necessitates, whenever audio signals shall be transmitted via such link, relatively complex encoding and decoding procedures as e.g. MPEG-codec, so as to result in high compression of the data being transmitted. Such encoding procedures nevertheless have the drawback of significant signal delay normally in excess of 50 msec and

are therefore not suited for binaural communication between hearing devices as here a real-time signal processing is important.

Other approaches to such binaural communication are based on wire-bound transmission. This necessitates the appliance of at least two wires by mini plugs to both hearing devices of the pair. Handling of a cable with two wires and especially of respective mini-plugs at the hearing devices is cumbersome for the individual, especially if such handling is performed as the hearing devices are already applied to the individual's ear. Therefore it is an object of the present invention to propose a binaural communication link which eliminates the drawbacks mentioned of wire-based links.

This object is resolved by the present invention by an approach as it is disclosed in the WO 01/39569 of the same applicant and inventors and which accords to the US-Patent Application No. 09/804 848.

Therein the solution of the above outlined problem is disclosed. According to the present invention there is thus proposed a method of establishing a binaural communication link between two hearing devices at an individual by at least two electric conductors in that one conductor is established by the individual's body and the at least one second conductor by a wire.

Thus the individual body with the respective body impedance is exploited as one of the said conductors so that there remains, in minimum, a single wire connection to be established between the hearing devices. Such a single wire

connection may very easily be handled and plugged in at the respective hearing devices by the individual.

By such a communication link either control signals to and from the respective hearing devices, but audio signals too, be it in analogue or in digital form, may be transmitted even bidirectionally. In a preferred embodiment there is thus proposed to bidirectionally transmit electrical signals between the hearing devices which are linked by the communication link according to the invention.

In a further preferred embodiment of the inventive method the hearing devices are not directly mutually linked by the said wire, but there is provided an electronic unit interconnected between the hearing devices by the communication link.

In a further preferred embodiment the electronic unit interconnected between the two hearing devices by the communication link according to the present invention comprises a receiver-/transmitter unit for wireless communication. Thereby signals received by wireless communication at such a unit are converted into signals which are transmitted via the said communication link with body-conductor to the hearing devices and/or by such an electronic unit signals received from the said two hearing devices by the said communication link with body-conductor are converted into wirelessly transmitted signals. Thus such an electronic unit operates as a wireless receiver-/transmit-unit to a remote transmitter-/receiver-unit by wireless communication for control signal transmission and/or for audio signal transmission. Such an electronic

unit may be any RF-link as e.g. a Blue-tooth unit. Thereby the said receiver-/transmitter unit may be applied, in one embodiment to one of the hearing devices which is operated as a master device, the second hearing device as a slave. In an other more preferred embodiment, the receiver-/transmitter unit is provided between the two hearing devices, which are thus operated on equal level of control.

In a most preferred embodiment the advantage of having only one wire to be connected either directly between the hearing devices or from the respective hearing devices to an interconnected electronic unit is exploited by realising connection of the wire to the hearing devices and/or to such electronic unit by a magnetic attraction. This leads to most easily handable plugging. The wire with a respective magnetic plug at one or at both of its ends may just be brought adjacent to the respective plug area at the hearing device or at the electronic unit. Connection will be practically automatically installed by that wire end being magnetically pulled onto said plug area at the respective device.

Thereby and in one preferred embodiment, by said magnetic attraction there is installed a conductive contact of the wire to an input tab at the at least one hearing device. Under a "conductive" material we understand a material with ohmic current conductance. Thereby such conductive electric contact may be realised by at least one magnetic member or ferro-magnetic member itself which provides for plugging magnetic attraction too.

In a further preferred mode where for instance electro-conductivity of a magnetic member or of a ferromagnetic member does not suffice for satisfying signal transmission, a conductive contacting is realised by the magnetic attraction - possibly additionally by a magnetic or ferromagnetic member - by at least one non-magnetic, metallic contact member, e.g. of aluminum, of copper, silver, gold, or of stainless steel or copper coated with gold and/or by conductive polymer.

In a further preferred mode said at least one wire is applied to at least one of the hearing devices and/or the electronic unit - mechanically - by magnetic attraction and - electrically - via a dielectric layer. Thereby a capacitive coupling is realised. By applying the wire to the at least one hearing device and/or electronic unit at both sides of the dielectric layer a conductive capacitance plate as e.g. of metal is established, thereby completing a capacitor structure. It is also possible to provide on both sides namely on the side of the hearing device or of the electronic unit, if provided, as well as on the side of the wire a dielectric layer. When such layers are joint once the connection is established, they form a dielectric double-layer. With provision of such dielectric layer or layers cleanability of the contact area is significantly improved e.g. on the side of the hearing device, where the dielectric layer may be part and be flush with the outer surface of the device's shell.

Because by the method of binaural linking according to the present invention only AC signals within a frequency band

above 10KHz are preferably to be transmitted, thereby especially digital signals, it is of no problem to transmit such signals via a series capacitance. Even if digital signals are thereby distorted they may easily be recovered by respective signal processing.

In a further preferred mode where the connection of the wire to at least one of the hearing devices and/or to the electronic unit, if provided, is established by magnetic attraction, this magnetic attraction is additionally exploited to provide for self-positioning of the wire's contact area to the hearing device and/or to the unit.

Thereby it becomes not even necessary that the individual manually and accurately positions the wire's contact area to the respective contact area of the hearing device or electronic unit, magnetic attraction suffices to mutually attract such areas and to accurately pull the areas into mutual correct positioning.

If necessary, by respective selection of polarities of magnets, on one hand on the hearing device or electronic unit, and, on the other hand, on the side of the wire, one can prevent that the wrong wire side is applied to a respective hearing device or electronic unit contact area.

If there is provided, as mentioned above, an electronic unit interconnected and communicating with the said two hearing devices by the communication link according to the present invention, such electronic unit has preferably a body contact electrode.

Such body contact electrode may be conductive, preferably at lest one of metallic and of a conductive polymer, or may be capacitive.

In a further preferred mode of realising the method according to the present invention the two hearing devices are in-the-ear or outside-the-ear hearing devices, and/or are hearing aid devices for therapeutic appliances.

In a still further preferred mode of the inventive method the wire connection and, if provided, also an electronic unit to be interconnected between the hearing devices is integrated within a head-worn assembly, thereby preferably within glasses for the individual. By such assembly, especially by glasses an accurate positioning of the wire connection is established without being even visually recognisable for other persons. In the above mentioned embodiment, especially where electric connection of the glasses-integrated wire is realised by magnetic attraction to the respective hearing devices, electric contact from the glasses-integrated wire may be established just by putting on the glasses. An interconnected electronic unit even for wireless communication with a remote transmitter-/receiver unit may also be integrated into the glasses with a respective transmission aerial.

The present invention is now to be described with the help of figures, which exemplify preferred embodiments of the method for establishing binaural communication links and of binaural hearing devices according to the present invention. The WO 01/39569 shall be incorporated into the present description by reference.

The figures show:

Fig. 1 schematically, the principle of the method of establishing a binaural communication link between hearing devices according to the present invention and, accordingly, of a binaural hearing device set according to the present invention;

Fig. 2 schematically and simplified, a set of binaural hearing devices according to a preferred form of the present invention and operating according to the method of the present invention, thereby establishing bidirectional audio signal and/or control signal communication;

Fig. 3 in a representation form in analogy to that of fig. 2 a set of binaural hearing devices according to the present invention and operating according to the method of the present invention, whereat one of the hearing devices is operated as a master device, the other as a slave;

Fig. 4 in a simplified representation of a preferred plugging system for establishing to a wire part of the binaural communication link according to the present invention electric contact by magnetic attraction to a counterpart;

Fig. 5 in a representation according to that of fig. 4 a further preferred plugging system;

Fig. 6 in a schematic form a further preferred wire-contacting and/or body-contacting arrangement

applied for establishing the communication link according to the present invention, and

Fig. 7 glasses with integrated communication link according to the present invention.

In fig. 1 there is shown, in a most generic and simplified representation form, the principle of the method according to the present invention and, accordingly, a set of binaurally operated hearing devices. At the left side -L- and the right side -R- ear of an individual there is applied a left-ear hearing device 1_L and respectively a right-ear device 1_R. Conceived as active hearing devices, each of these devices comprises an electrical to mechanical converter 3_L and 3_R being e.g. respective loudspeakers. These converters $3_{L,R}$ are operated by respective electronic units 5_L and 5_R, which comprise, for digital hearing devices, customarily a digital processing unit DSP. There is further provided a communication link between the two hearing devices 1_L and 1_R schematically denoted in fig. 1 by the reference No. 7. This communication link is wire-bound and therefore comprises at least two wires, which link the two hearing devices 1_L and 1_R and thereby especially their electronic units 5_L and 5_R.

According to the present invention one of these at least two wires forming the communication link 7 between the two hearing devices 1_L and 1_R is formed by a body conductor 7_B, which is realized by the individual's body between a contact area 9_L, whereat a body electrode 11_L at hearing device 1_L contacts the individual's body and a contact area 9_R, whereat a body electrode 11_R at the hearing device 1_R

contacts individual's body. The body conductor 7_B is shown in fig. 1 in dashed lines with the impedance Z_B representing the individual's body impedance between the said two contact areas 9_L and 9_R. Besides of this body conductor 7_B there is provided at least one wire conductor 7_W completing the communication link 7. Clearly more than one communication link 7 may, if necessary, be provided between the hearing devices 1_L and 1_R, which leads to multiple wire conductors 7_W with commonly a body conductor 7_B.

As will be shown by examples, the communication link 7 may be operated to perform communication in a selected direction, e.g. from left to right, or and preferably to perform communication bidirectionally as shown in fig. 1 by the double-arrow F.

Further, the communication via the communication link 7 according to the present invention may be for audio signals converted into a respective electronic form, especially into digital form, and/or for control signals for the respective electronic units 5_L and 5_R. Thereby the communication link 7 may be established by providing the wire connector 7_W directly interconnecting the two hearing devices 1_L and 1_R, at another preferred mode of realizing the present invention there may be provided a further electronic unit as shown in dashed pointed lines in fig. 1 and denoted by the reference No. 13 being interconnected between the hearing devices 1_L and 1_R and being electrically connected to at least one, preferably to both hearing devices 1_L and 1_R respectively with at least one

wire connector. An electronic unit is further connected by a further body contact electrode 11_{13} to the individual's body at a contact area 9_{13}.

Thereby the electronic unit 13 may comprise (not shown) a transmitter/receiver unit for wireless communication C with a remote receiver/transmitter unit (not shown) so as to receive in wireless communication audio signals and/or control signals to be transmitted to the hearing devices 1_L and/or 1_R. Additionally or alternatively such transmitter/receiver unit at the electronic unit 13 may communicate control signals from and/or towards at least one of the hearing devices 1_L and 1_R towards and/or from a remote control unit. The electronic unit 13 may thus be conceived as any RF-link, e.g. as a Blue-tooth device.

In fig. 2 there is shown one specific embodiment of binaurally operated hearing devices with a communication link 7 according to the present invention. The two hearing devices 1_R and 1_L concomitantly operate for specific beam forming.

It is known that by providing microphones at a predetermined mutual distance and respective treating of the electric output signals of such microphones, beam forming may be achieved based on the fact of mutual phase difference or time lag with which an acoustical signal from an acoustical source impinges upon the two microphones. Such a beam forming is e.g. the well-known "delay and add" method

According to fig. 2 both hearing devices have respective microphones 15_L and 15_R, the outputs thereof being

operationally connected to respective analogue to digital converters 17_L and 17_R.

At each of the hearing devices there is further provided, as schematically shown with the units 19_L and 19_R, a controlled time-multiplexer unit, which is operated by a respective time control unit 20_L and 20_R in synchronism. As schematically shown in fig. 2 in one first time frame '1' a digitalized output signal of microphone 15_L is led, as an audio signal, via communication link 7 to the input of digital processing unit DSP_R simultaneously with a digitalized output signal of microphone 15_R. Vice versa, in a second time frame '2' the digitalized output signal of microphone 15_R is led to the input of digital processing unit DSP_L altogether with the digitalized output signal of microphone 15_L. Thereby, staggered in time, the digital processing units DSP of both hearing devices receive at their respective inputs digitalized audio signals of both microphones. Synchronising of the time control units 20_L and 20_R is also performed via the communication link according to the present invention.

Due to the fact that both digital processing units DSP receive audio information of both microphones, both may perform beam forming.

Thereby, it becomes evident that it is absolutely possible to only provide one of the two digital processing units DSP_L or DSP_R with digitalized audio signals of both microphones and thereby to perform beam forming only at one of the two hearing devices 1_L or 1_R. In such case digitalized audio signals may be one-directionally led via

the communication link 7 according to the present invention from one hearing device to the other.

One of the two hearing devices acts in such a case as the beam forming hearing device, which may be said with respect to beam forming to act as a master hearing device, with respect to the second hearing device acting as a slave hearing device.

In fig. 3 there is shown a further preferred embodiment of a set of binaurally operated hearing devices communicating by the communication link 7 according to the present invention. Thereby this embodiment shows an example of one hearing device, namely device 1_L acting as a master with respect to the second hearing device 1_R acting as a slave. According to fig. 3 only the hearing device 1_L has a microphone or microphone arrangement 15_L. Beam forming is performed after audio signal digitalisation (not shown in fig. 3) at the digital processing unit DSP_L. Via the communication link 7 according to the present invention, a digitalized audio signal is communicated via link 7 to the second hearing device 1_R with appropriate phasing e.g. according to the mutual distance of the two hearing devices 1_L and 1_R at the individual, and this digitalized audio signal is directly electrically input to the digital processing unit DSP_R of the hearing device 1_R. Thus, hearing device 1_L acts as master hearing device with respect to a slave hearing device 1_R.

It is evident that further master/slave concepts via the communication link 7 according to the present invention may be realized also for control signals, one of the two

hearing devices receiving e.g. by wireless communication control signals and transmitting control signals to the slave hearing device. In inverse direction acknowledgement signals, also being considered as control signals, may be retransmitted from the slave hearing device to the master hearing device.

Departing from the main object of the present invention the communication link 7 according to the present invention has the tremendous advantage of necessitating only one wire interconnecting, according to fig. 1, either directly or via a further electronic unit 13, the two hearing devices 1_L and 1_R. Thus, only one wire must be plugged to at least one of the two hearing devices 1_L and 1_R according to fig. 1, at tap 22_L and/or at tap 22_R. Although and with respect to handling plugging-in a hearing device communication link cable at one or at both of the hearing devices, it is evident that plugging-in one wire cable is already significantly easier than plugging-in a multiple wire cable, a further improvement thereabout is reached by providing, as will now be exemplified, plugging-in of the one-wire conductor at at least one or, preferably, at both hearing devices by magnetic attraction.

Fig. 4 schematically shows a plugging area 22_{LR} according to fig. 1. If an electronic unit 13 is provided, such plugging-in system may also be provided to contact unit 13 as is shown in fig. 1 at 22_{13} by the communication link wires 7_W.

Thereby at least one end of wire 7_W and/or the respective contact area at one or both of the hearing devices 1_L, 1_R

and/or at unit 13 are provided with a magnet arrangement. According to fig. 4 and as an example the end of the wire 7_W is provided with a magnet arrangement 24. The counterpart mechanical contact pad 26 may thereby be of ferromagnetic material or may be as well a magnet arrangement.

Thereby, mechanically, the end of wire 7_W needs only to be brought adjacent to the mechanical contact area 26 to be attracted and positioned in intimate contact therewith by permanent magnet action.

Nevertheless, this contacting by magnet/magnet contact or by magnet/ferromagnetic material contact needs not directly establish the electric contact. In some instances electro-conductivity and mutual contacting of magnet/magnet or magnet/ferromagnetic material contacts may not suffice for electric communication purposes.

An accordingly conceived plug-in arrangement is shown in fig. 5 in the same schematic representation form as that of fig. 3. The difference to the embodiment of fig. 4 is that the magnetic arrangements and counterparts 24/26 are only provided for mechanical attraction purposes, whereas electric contacting of the wire 7_W to the hearing device or, respectively, the electronic unit 13 is performed by non-magnetic contact pads 24_e and 26_e, e.g. of aluminum, copper, gold or of stainless steel or copper coated with gold and/or by a conductive polymer member.

So as to further improve ease of plugging-in the wire conductor 7_W making part of the communication link 7 according to the present invention and by magnetic

attraction, there may be installed automatic self-positioning of the contact pads 24e, 26e as shown in fig. 5 e.g. by providing guidance surfaces 28 so as to properly and automatically position the wire end contact 24, 24_e. This might especially be important in the case where, according to fig. 5 a pair of locally distinct electric contact pads 24_e and 26_e is provided having to be properly mutually positioned one upon the other.

As will now be shown with the help of fig. 6, electrical signal transmission from the wire 7_W to at least one of the hearing devices 1_L and 1_R and possibly even to the electronic unit 13 as of fig. 1 and/or from the respective unit (hearing devices and/or unit 13) to individual's body via the contact area 9 as of fig. 1 needs not necessarily be established by a conductive contact e.g. by a metallic/metallic or metallic/electrolytic contact (in case of body electrodes), but may be established capacitively, especially for transmitting digital signals representing audio signals or being control signals.

According to fig. 6 one end of the wire 7_W making part of the communication link according to the present invention is formed by a conductive plate as by a metal or conductive polymer layer 30 embedded in an isolating plugging arrangement 32 as schematically shown. On the opposite side, thus be it on one or both of the hearing devices or on the electronic unit 13, there is provided a second conductive plate as by a metal or conductive polymer layer 34, which is covered towards the outside by dielectric material, e.g. by a layer 36 of dielectric material. This

layer may be unitarily formed the shell or housing of the hearing device considered or of the electronic unit 13. By bringing the conductive plate 30 in intimate contact with the surface of the dielectric layer 36, conductive plate or layer 30, dielectric layer 36 and conductive plate or layer 34 form or establish a capacitor in series with wire 7_W and operationally connected, as schematically shown, e.g. to a preamplifier stage 38 at the hearing device or at the unit 13. Especially for transmitting digital signals, even if such digital signals are distorted by the capacitive - 30/36/34- electric link, it is of no problem to recover the digital signal e.g. at the preamplifier stage 38.

As further shown in fig. 6 additionally or instead of capacitively coupling the wire 7_W to the electronic unit at unit 13 and/or to at least one of the hearing devices 1_L, 1_R also the respective body contact electrode as of 11 of fig. 1 may be conceived as a series capacitance electrode. Thereby, at electronic unit 13 or at at least one of the hearing devices 1_L, 1_R the body contact electrode comprises a conductive plate as a metallic layer or a layer of conductive polymer 40 electrically connected to the respective electronic unit, as according to fig. 5 to preamplifier stage 38. The conductive plate or layer 40 is covered by a dielectric layer 42 in analogy to the explanations given with respect to dielectric covering of conductive plate or layer 34. By contacting the electrolytic conductance body BO of the individual so as to establish the body conductor 7_B of fig. 1, there is again formed a series capacitance 40/42/BO.

Providing the dielectric material layers 36 and/or 42 additionally improves cleanability and prevents electrode corrosion.

It is perfectly clear to the skilled artisan that a capacitive signal coupling as shown in fig. 6 may also be realised by covering the other conductive plate 30 by a dielectric layer or by covering both conductive plates 30 and 34 by such dielectric layers, thereby establishing a double-layer dielectricum. Thereby, as a very intimate contact of the surfaces establishing a series capacitance coupling should be realized, an electroconductive gel may be applied between these surfaces to be contacted, e.g. a gel as is used or applied to cardiographic electrodes.

Bringing the parts to be contacted into mutual intimate contact so as to establish the series capacitance may be realized in any known way, as by clip-fixation, bayonet fixation etc. Nevertheless, in a most preferred embodiment, this contacting is realized, as shown in fig. 6, by magnetic attraction too.

In fig. 6 both parts to be contacted are provided with respective magnet arrangements 24a and 24b. If both these parts are provided with permanent magnets, as shown in fig. 6, by selection of the respective direction of polarity P one may prevent that the wire 7_W may be brought into contact at a predetermined contact area, be it of a hearing device and/or of the electronic unit. With the direction of polarities P selected according to fig. 6 the two parts are attracted, whereas if the polarity P e.g. at the plug 32 of wire 7_W is inverted as shown in dashed lines, it will not

be possible to contact the plug 32 to the area as shown in fig. 6 due to magnetic repulsion.

Instead of establishing a capacitive contact to the individual's body BO as was explained before a conductive contact member may directly be applied and thereby e.g. for improving comfort to the individual especially a conductive member of conductive plastic material, especially of conductive polymer.

In a further preferred embodiment of the present invention and according to fig. 7 the wire 7_W is integrated into glasses. Thereby, the wire 7_W is contacted with the respective right-hand and left-hand hearing devices (not shown in fig. 6) at schematically shown contact areas 45, which preferably are realized for establishing contact by magnetic attraction, as shown in the figs. 4 to 6. If provided, an electronic unit 13 may also be integrated into the glasses. Thus, by simply applying the glasses, the communication link 7 according to the present invention between the binaurally operated hearing devices is established, which is largely facilitated by conceiving contacting at the areas 45 to the respective hearing devices, as was described, by magnetic attraction.